Lect. 4

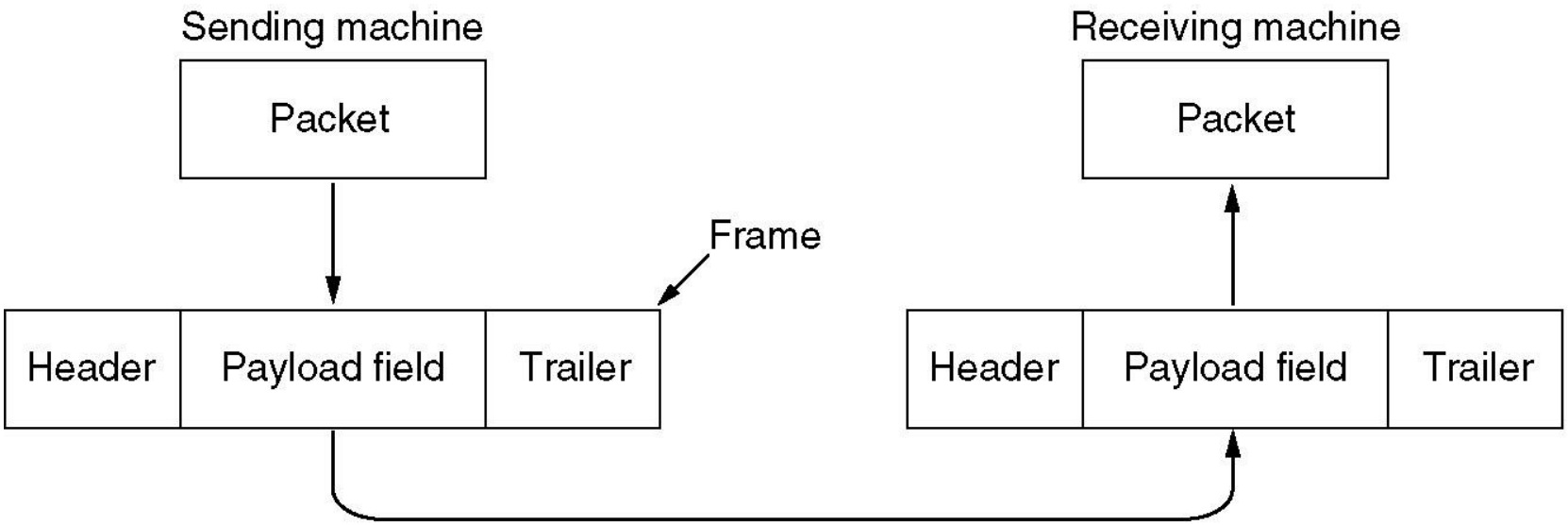
Data Link Layer

Functions of the Data Link Layer

- **Services Provided to the Network Layer**: Provide service interface to the network layer
- **Framing**: Identifies the start and end of a frame.
- **Error Control**: Detects and corrects transmission errors
- **Flow Control**: Regulating data flow
  - Slow receivers not swamped by fast senders
- **Media Access Control:** Controls when computers transmit.
- **Addressing**

Functions of the Data Link Layer (2)

Relationship between packets and frames.



Types of services provided to the Network Layer

- Unacknowledged Connectionless service
- Acknowledged Connectionless service
- Acknowledged Connection-Oriented service

Unacknowledged Connectionless service:

- Losses are taken care of at higher layers
- Used on reliable medium like coax cables or optical fiber, where the error rate is low.
- Appropriate for voice, where delay is worse than bad data.

Acknowledged Connectionless service

- Useful on unreliable medium like wireless.
- Acknowledgements add delays.
- Adding ack in the DLL rather than in the NL is just an optimization and not a requirement. Leaving it for the NL is inefficient as a large message (packet) has to be resent in that case in contrast to small frames here.
- On reliable channels, like fiber, the overhead associated with the ack is not justified.

Acknowledged Connection-oriented service:

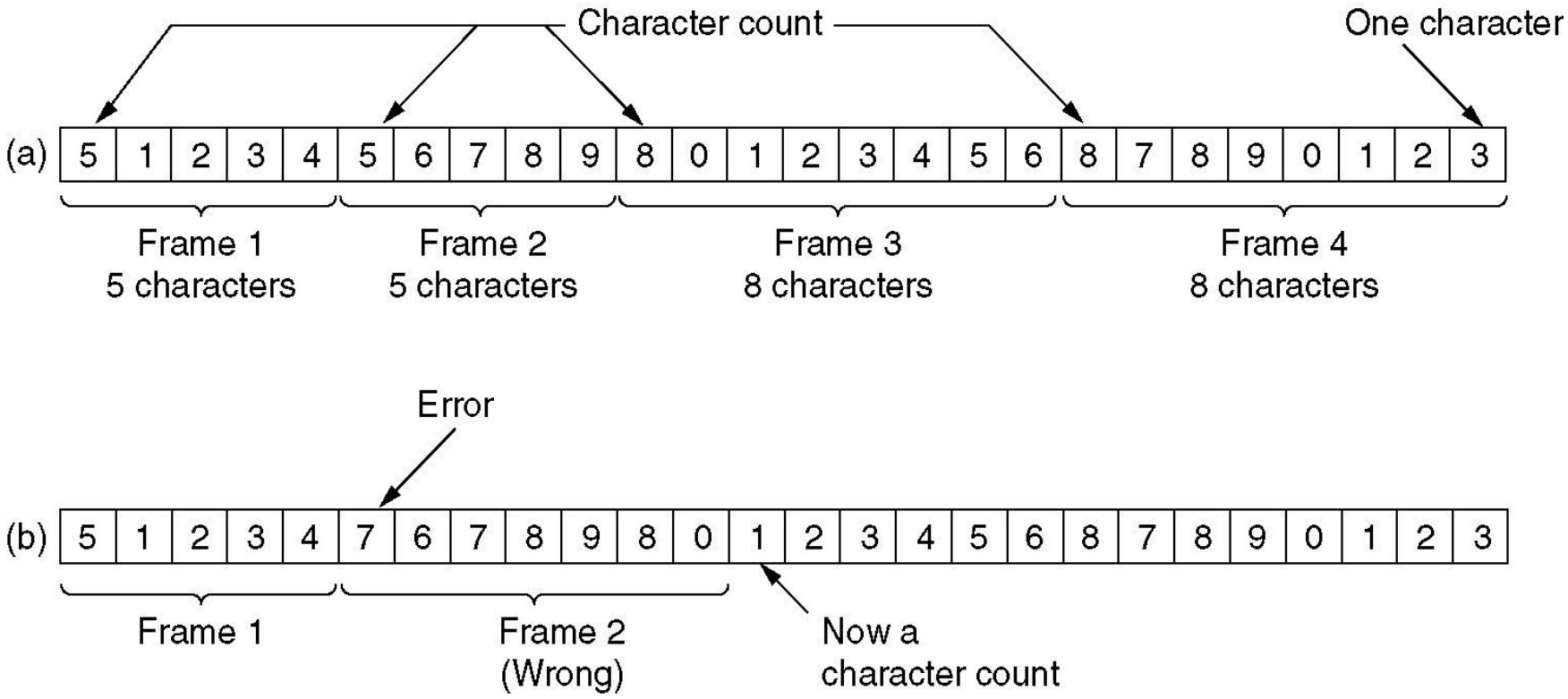
- Most reliable.
- Guaranteed service –
  - Each frame sent is indeed received
  - Each frame is received exactly once
  - Frames are received in order
- Special care has to be taken to ensure this in connectionless services

Framing

- Character Count
- Flag bytes with byte stuffing
- Flag bytes with bit stuffing

Framing with Character Count

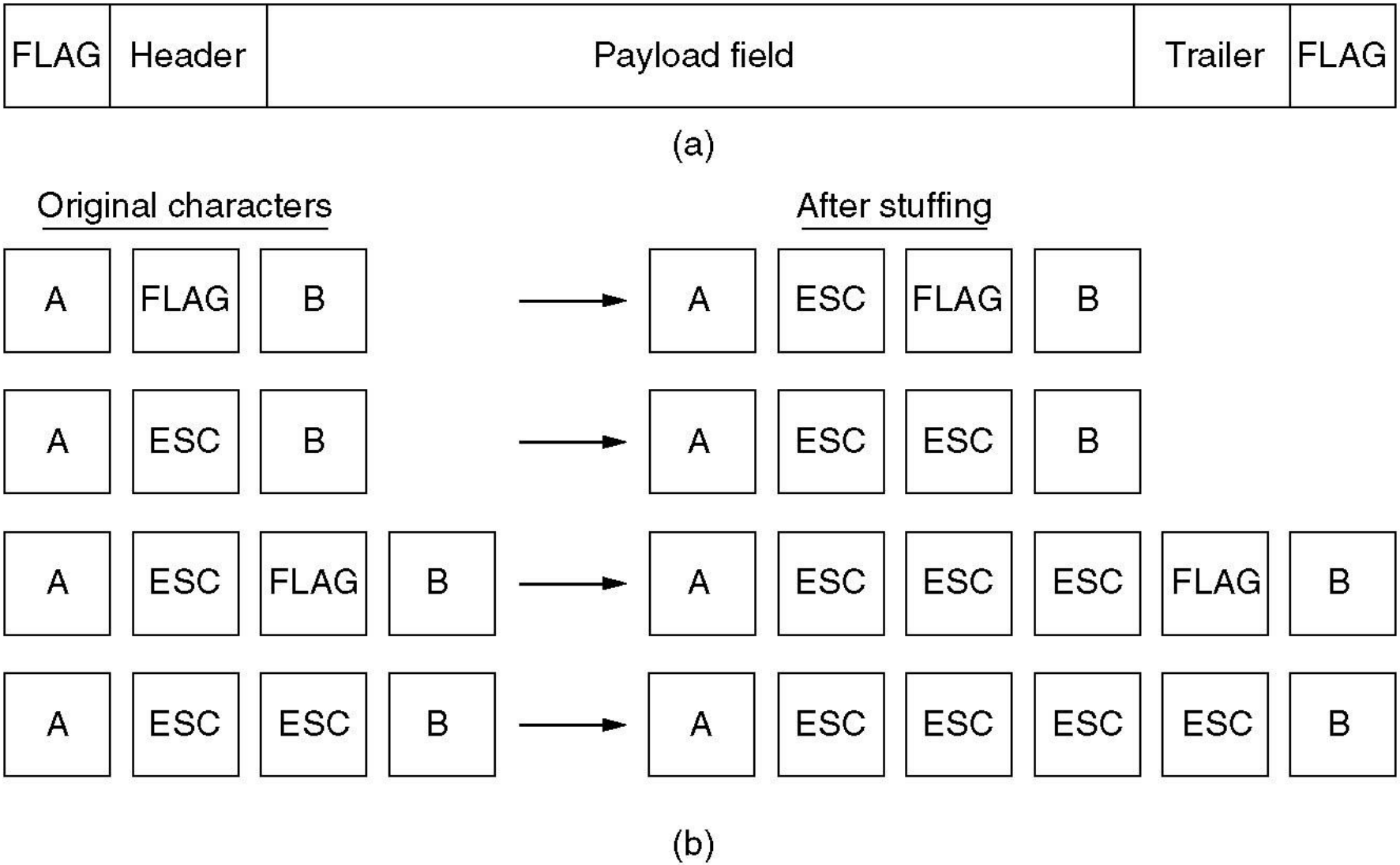
A character stream. (a) Without errors. (b) With one error.



Problem with Framing with CC

- What if the count is garbled.
- Even if with checksum, the receiver knows that the frame is bad there is no way to tell where the next frame starts.
- Asking for retransmission doesn't help either because the start of the retransmitted frame is not known
- No longer used.

Framing with byte stuffing

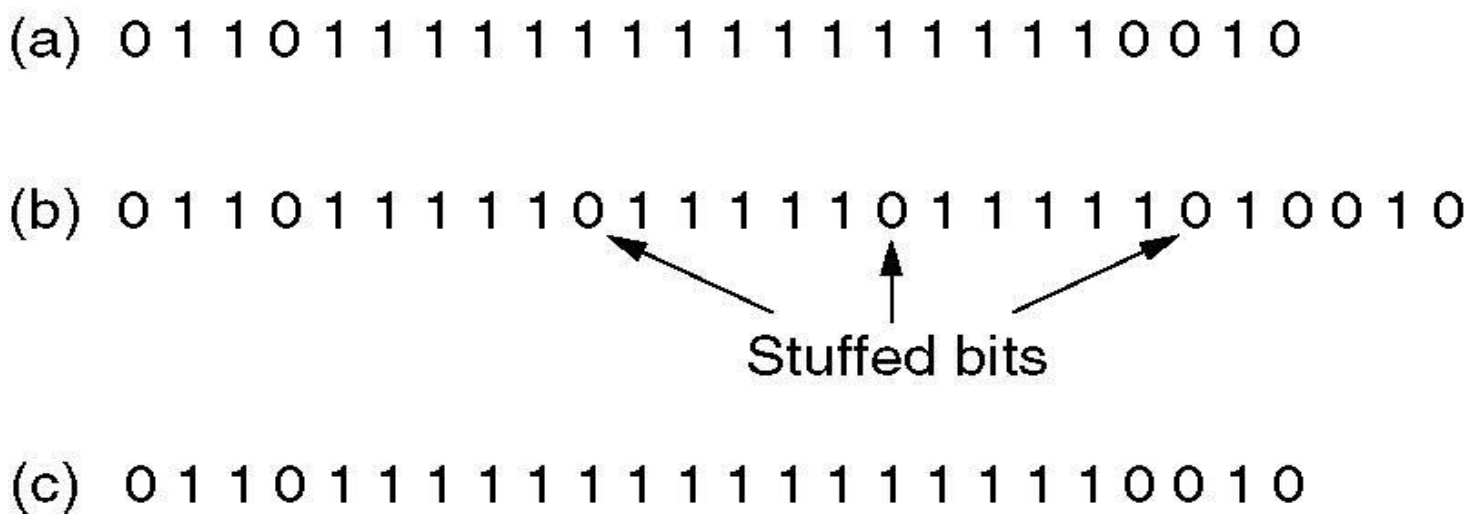


- Any pattern used for the flag could also be part of the information. To fix this problem, **a byte-stuffing** strategy was added to character-oriented framing. In **byte stuffing (or character stuffing)**, a special byte is added to the data section of the frame when there is a character with the same pattern as the flag. The data section is stuffed with an extra byte. This byte is usually called the escape character (ESC), which has a predefined bit pattern.
- Whenever the receiver encounters the ESC character, it removes it from the data section and treats the next character as data, not a delimiting flag.

Framing with byte stuffing

- Problem : fixed character size : assumes character size to be 8 bits : can't handle heterogeneous environment.
- Character-oriented protocols present a problem in data communications. The universal coding systems in use today, such as Unicode, have 16-bit and 32-bit characters that conflict with 8-bit characters. We can say that in general, the tendency is moving toward the bit-oriented protocols that we discuss next.

Framing with bit stuffing



Bit stuffing

(a) The original data.

(b) The data as they appear on the line.

(c) The data as they are stored in receiver's memory after destuffing.

Error Control

- Error control includes both error detection and error correction.
- It allows the receiver to inform the sender if a frame is lost or damaged during transmission and coordinates the retransmission of those frames by the sender.
- Error control in the data link layer is based on automatic repeat request (ARQ). Whenever an error is detected, specified frames are retransmitted.

Error Detection and Correction

- In some cases it is sufficient to detect an error and in some, it requires the errors to be corrected also. For eg.
  - On a reliable medium : ED is sufficient where the error rate is low and asking for retransmission after ED would work efficiently (party check code)
  - In contrast, on an unreliable medium : Retransmission after ED may result in another error and still another and so on. Hence EC is desirable. (Hamming codes)

Flow Control

- Flow control coordinates the amount of data that can be sent before receiving acknowledgement
- It is one of the most important functions of data link layer.
- Flow control is a set of procedures that tells the sender how much data it can transmit before it must wait for an acknowledgement from the receiver.
- Receiver has a limited speed at which it can process incoming data and a limited amount of memory in which to store incoming data.
- Receiver must inform the sender before the limits are reached and request that the transmitter to send fewer frames or stop temporarily.
- Since the rate of processing is often slower than the rate of transmission, receiver has a block of memory (buffer) for storing incoming data until they are processed.

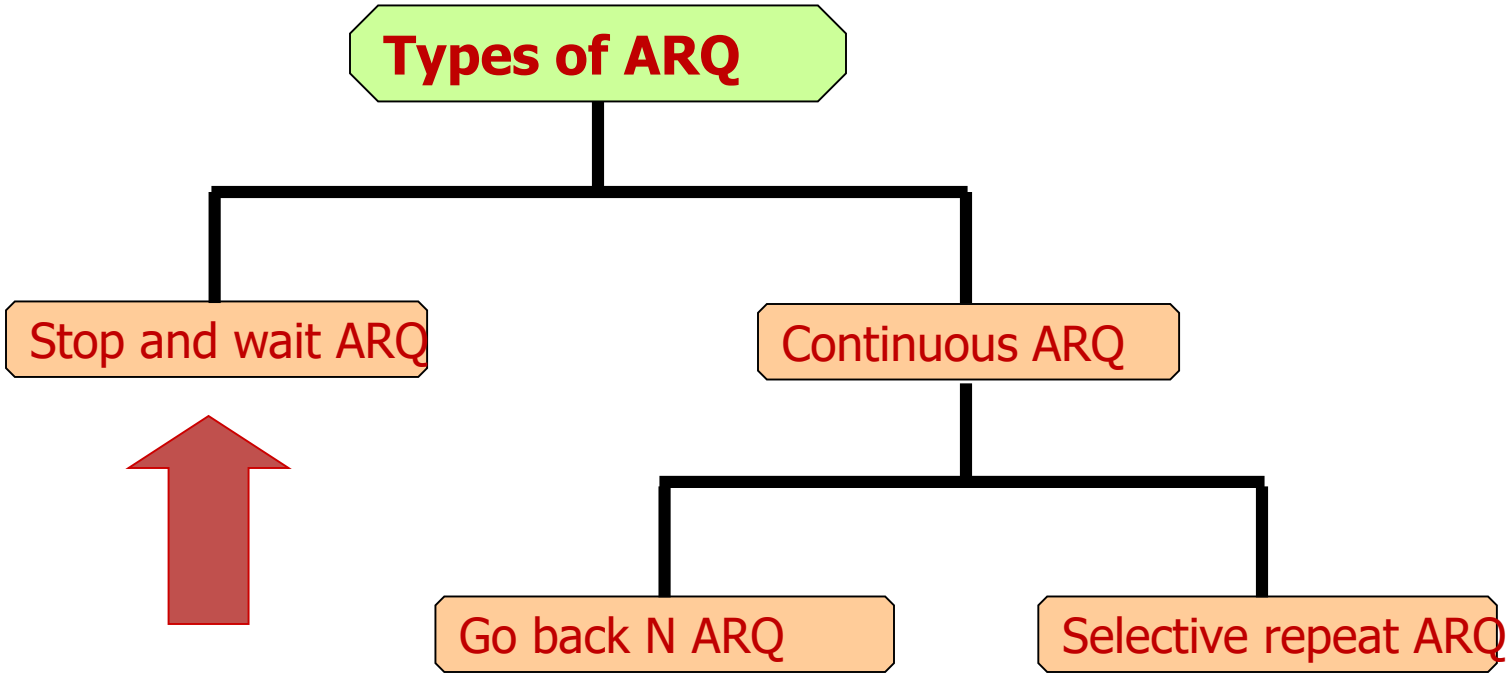
Automatic repeat request (ARQ)

- Forward Error Correction (FEC) uses codes to correct errors at the receiver.
- The alternative approach is error detection with automatic repeat request.
- ARQ detects errors and asks the transmitter to retransmit erroneous blocks.
- The receiver uses positive acknowledgment (ACK) or negative ACK (NACK) to inform the transmitter.
- Some systems use only ACK or both ACK+NAK.

Automatic repeat request (ARQ)

- There are two ARQ Schemes; namely, stop and wait ARQ and continuous ARQ.
- The choice of the scheme is based on:
  - ❑ the channel propagation delay.
  - ❑ the packet size.
  - ❑ the bit error rate on the channel.
  - ❑ the trade-off between channel utilization and nodal storage.
- A copy of transmitted packet is retained at transmitter until a confirmation is received.

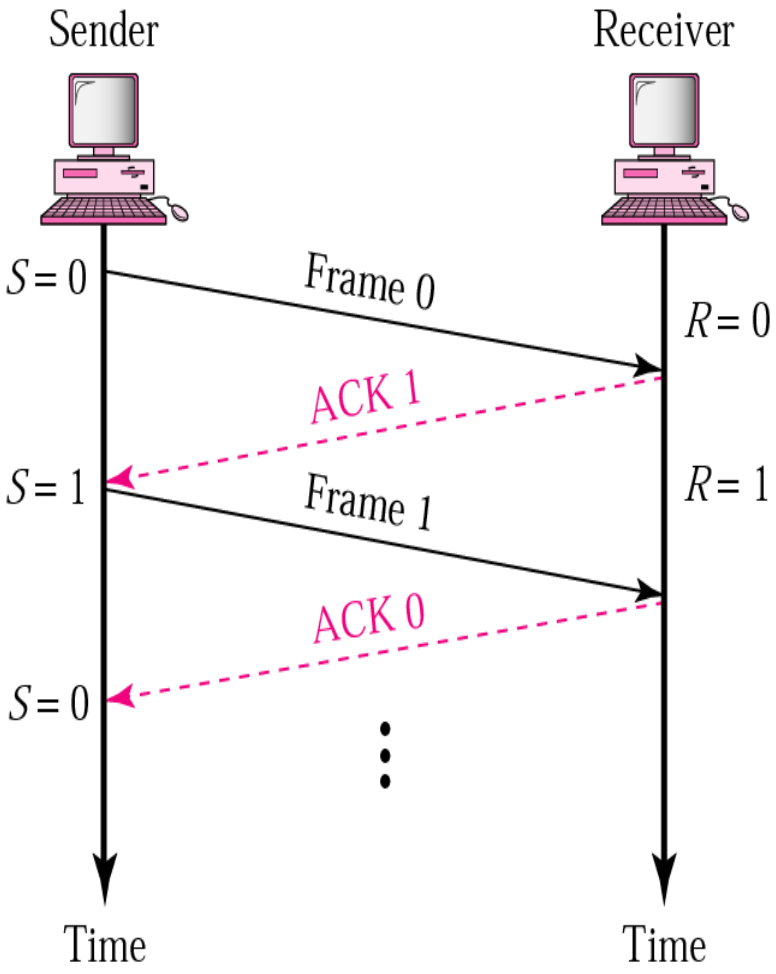
Types of ARQ


Types of ARQ
Stop and wait ARQ
Continuous ARQ
Go back N ARQ
Selective repeat ARQ

Stop–and-Wait ARQ

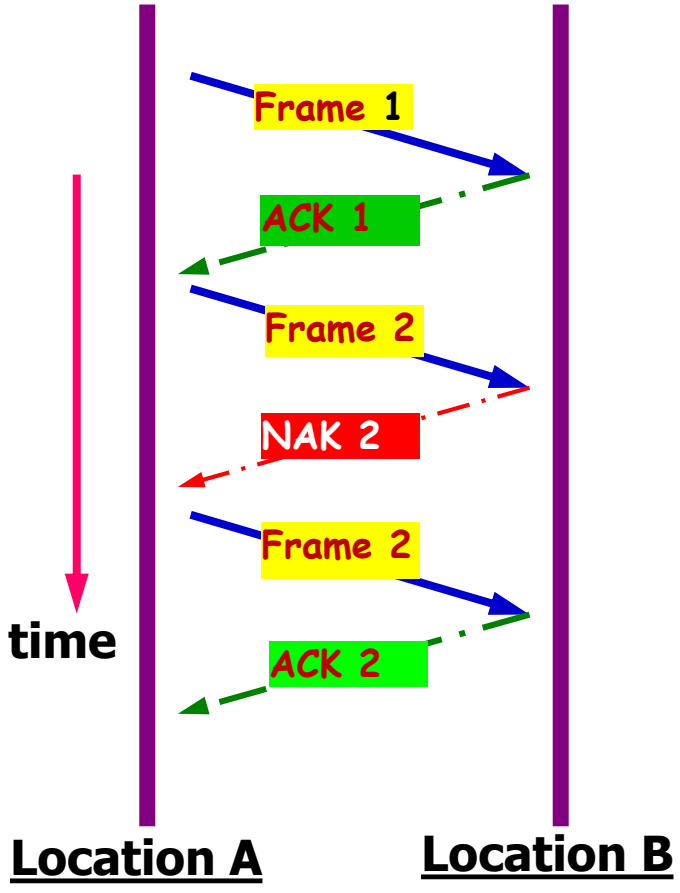
- The sending node sends one block of data and waits for an ACK before transmitting the next block.
- If an ACK is received, the stored copy of the block at the transmitter is discarded and next block is transmitted.
- If NAK is discovered, the block is retransmitted.

Stop-and-Wait

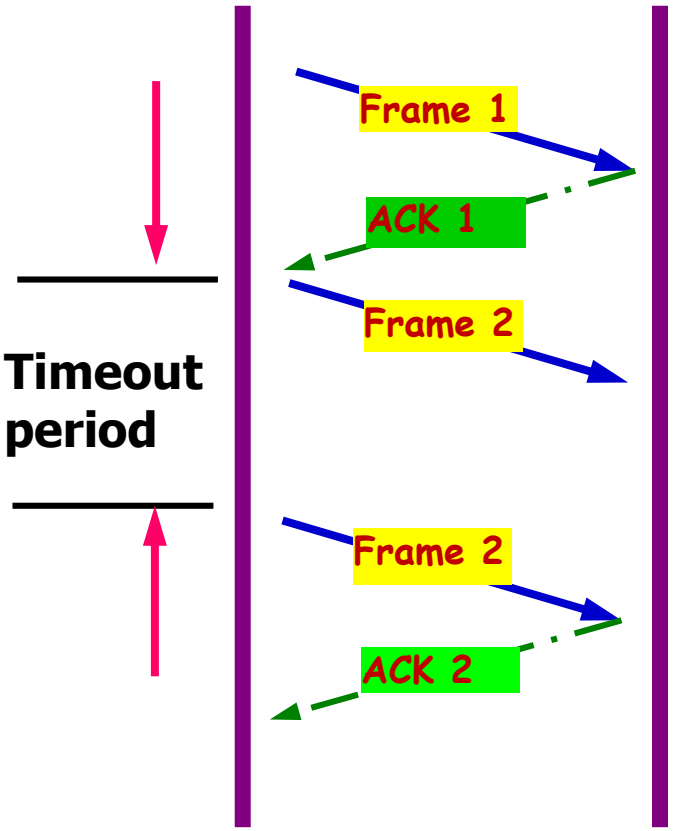


- Sender keeps a copy of the last frame until it receives an acknowledgement.
- For identification, both data frames and acknowledgements (ACK) frames are numbered alternatively 0 and 1.
- Sender has a control variable (S) that holds the number of the recently sent frame. (0 or 1)
- Receiver has a control variable ® that holds the number of the next frame expected (0 or 1).
- Sender starts a timer when it sends a frame. If an ACK is not received within a allocated time period, the sender assumes that the frame was lost or damaged and resends it
- Receiver send only positive ACK if the frame is intact.
- ACK number always defines the number of the next expected frame

Stop–and-Wait ARQ

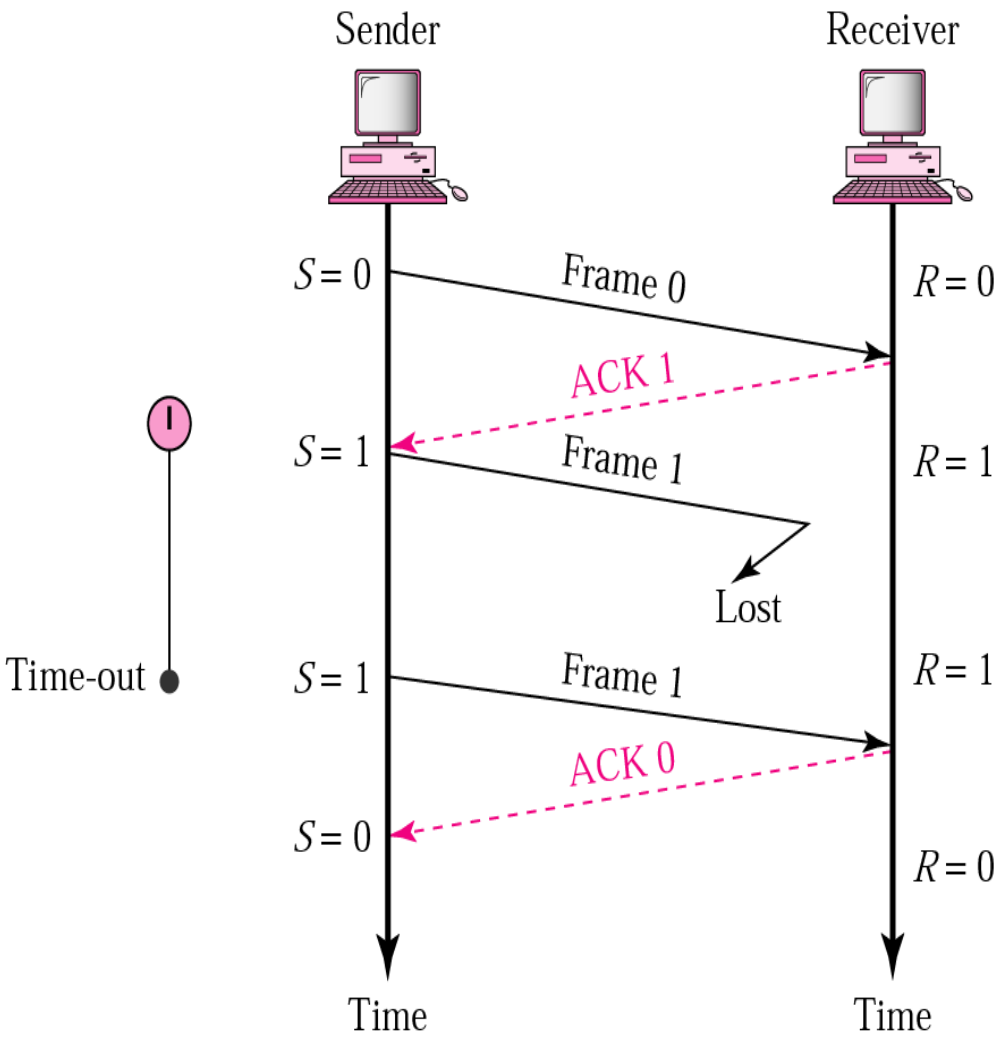


ACK & NAK



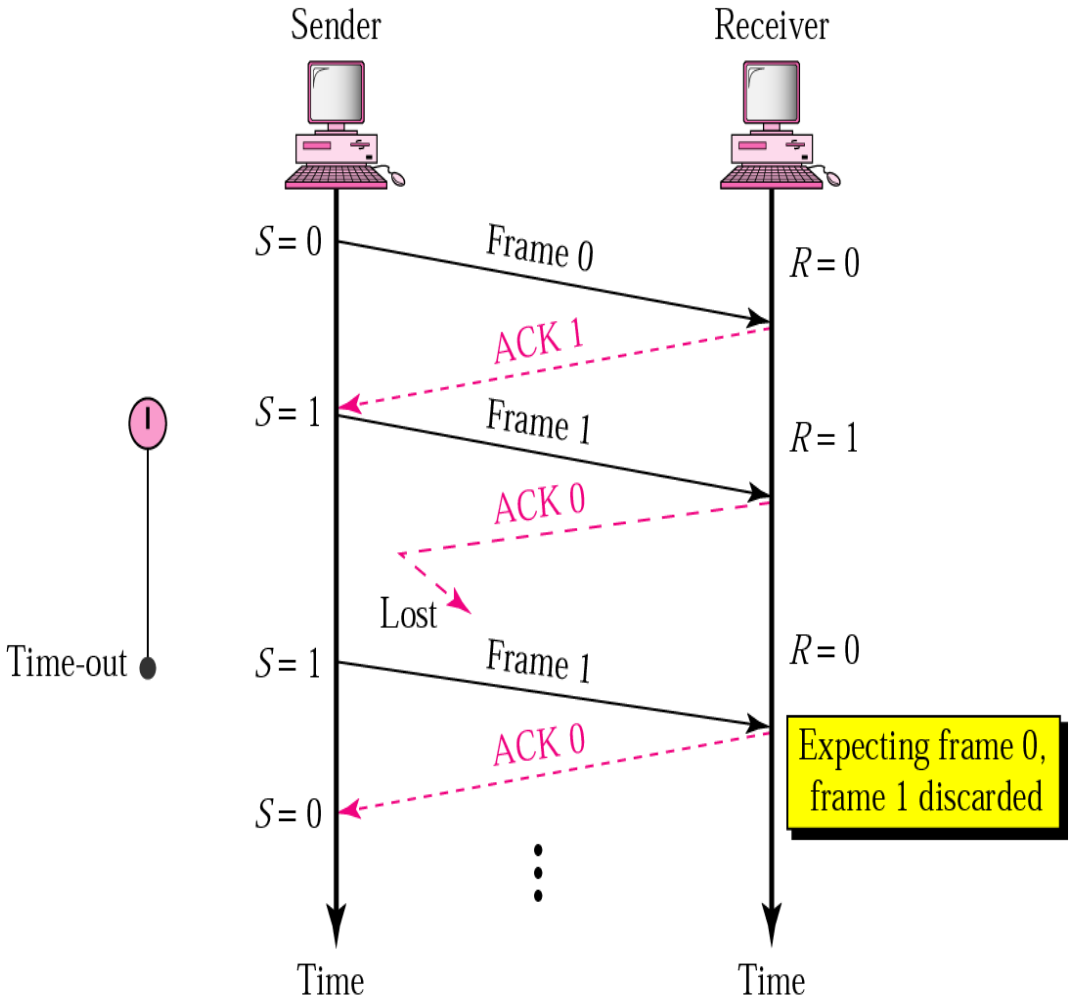
ACK only

Stop-and-Wait ARQ, lost ACK frame



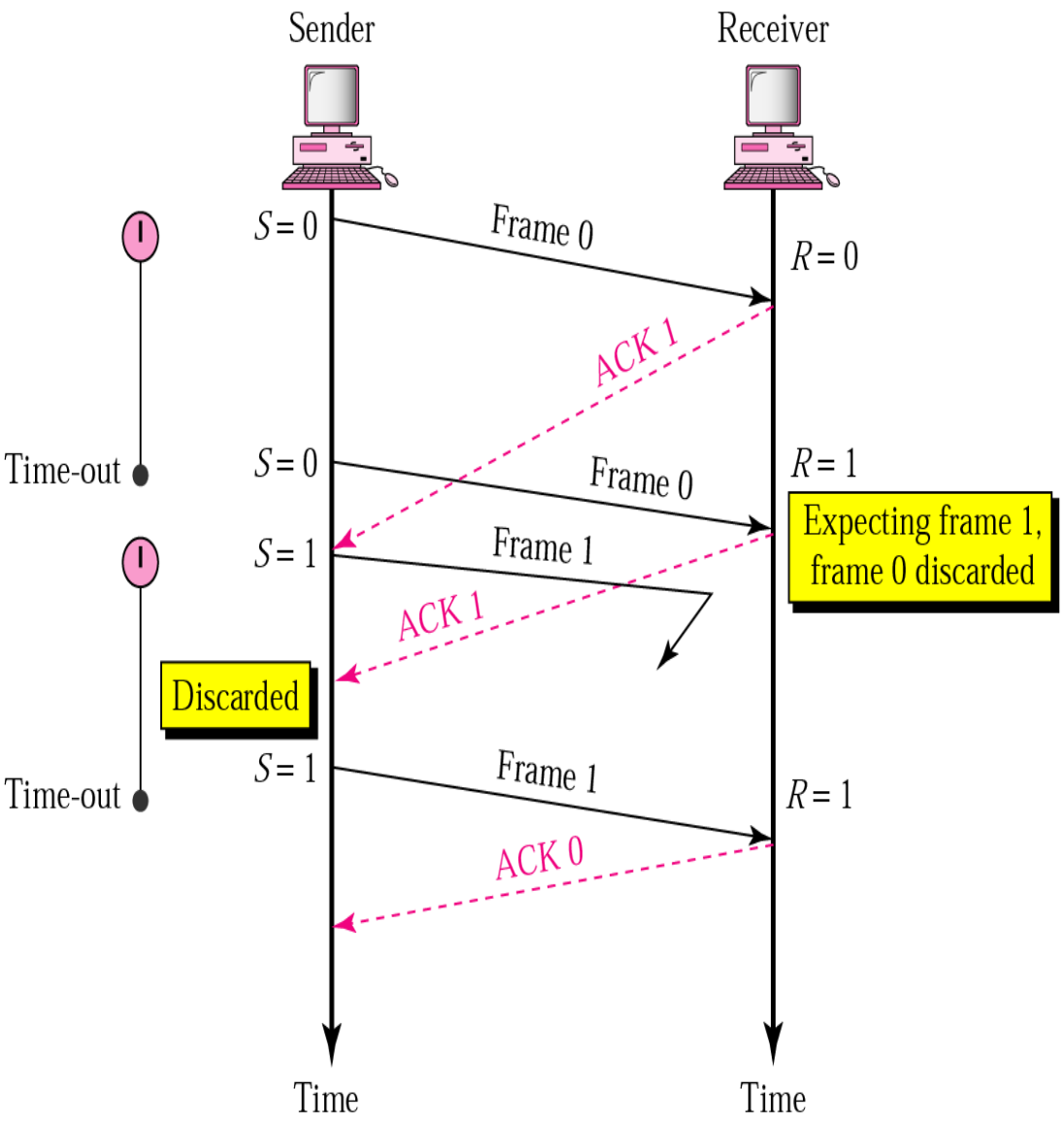
- When a receiver receives a damaged frame, it discards it and keeps its value of R.
- After the timer at the sender expires, another copy of frame 1 is sent.

Stop-and-Wait, lost ACK frame



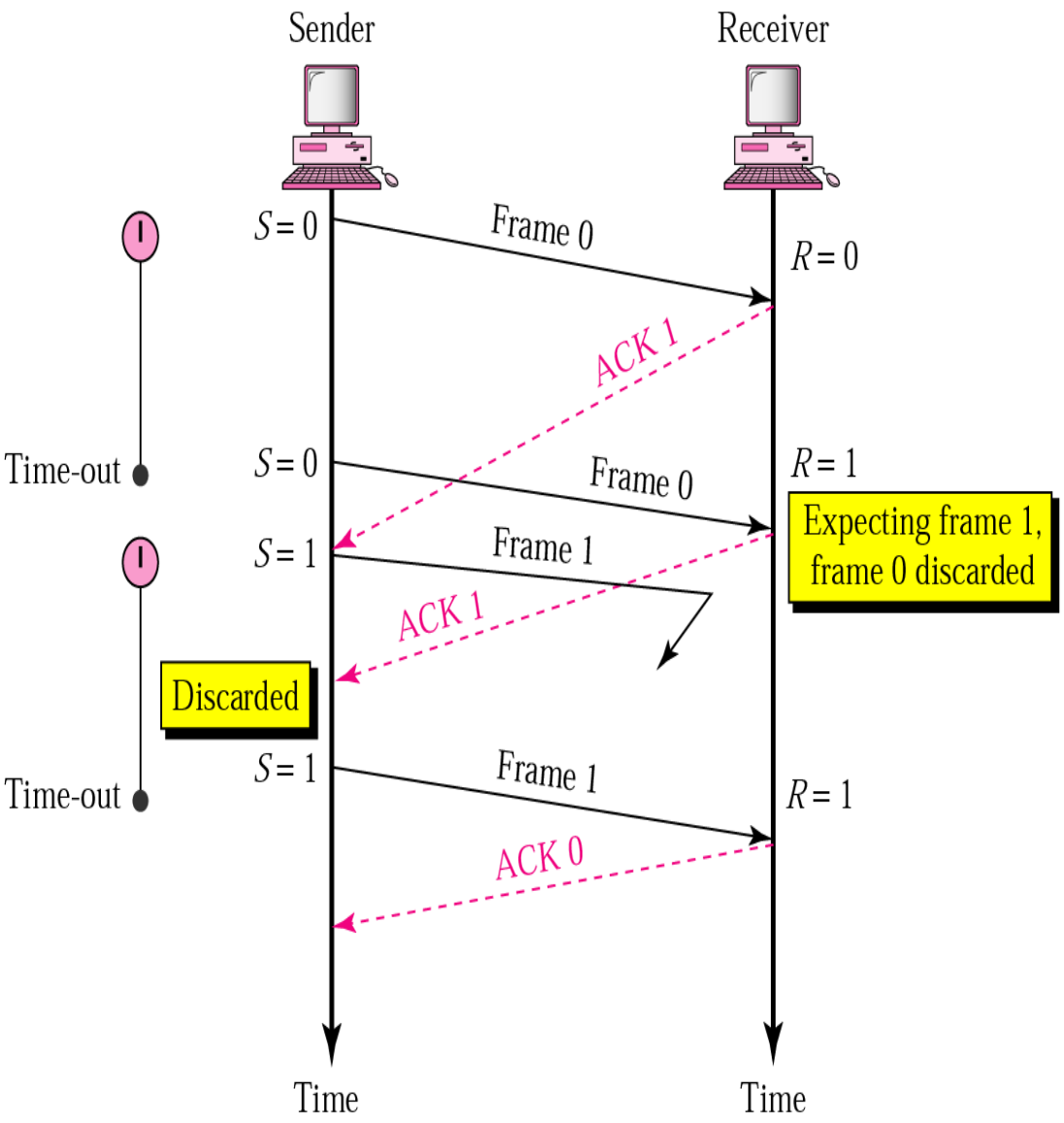
- If the sender receives a damaged ACK, it discards it.
- When the timer of the sender expires, the sender retransmits frame 1.
- Receiver has already received frame 1 and expecting to receive frame 0 (R=0). Therefore it discards the second copy of frame 1.

Stop-and-Wait, delayed ACK frame



- The ACK can be delayed at the receiver or due to some problem
- It is received after the timer for frame 0 has expired.
- Sender retransmitted a copy of frame 0. However, R =1 means receiver expects to see frame 1. Receiver discards the duplicate frame 0.
- Sender receives 2 ACKs, it discards the second ACK.

Stop-and-Wait, delayed ACK frame



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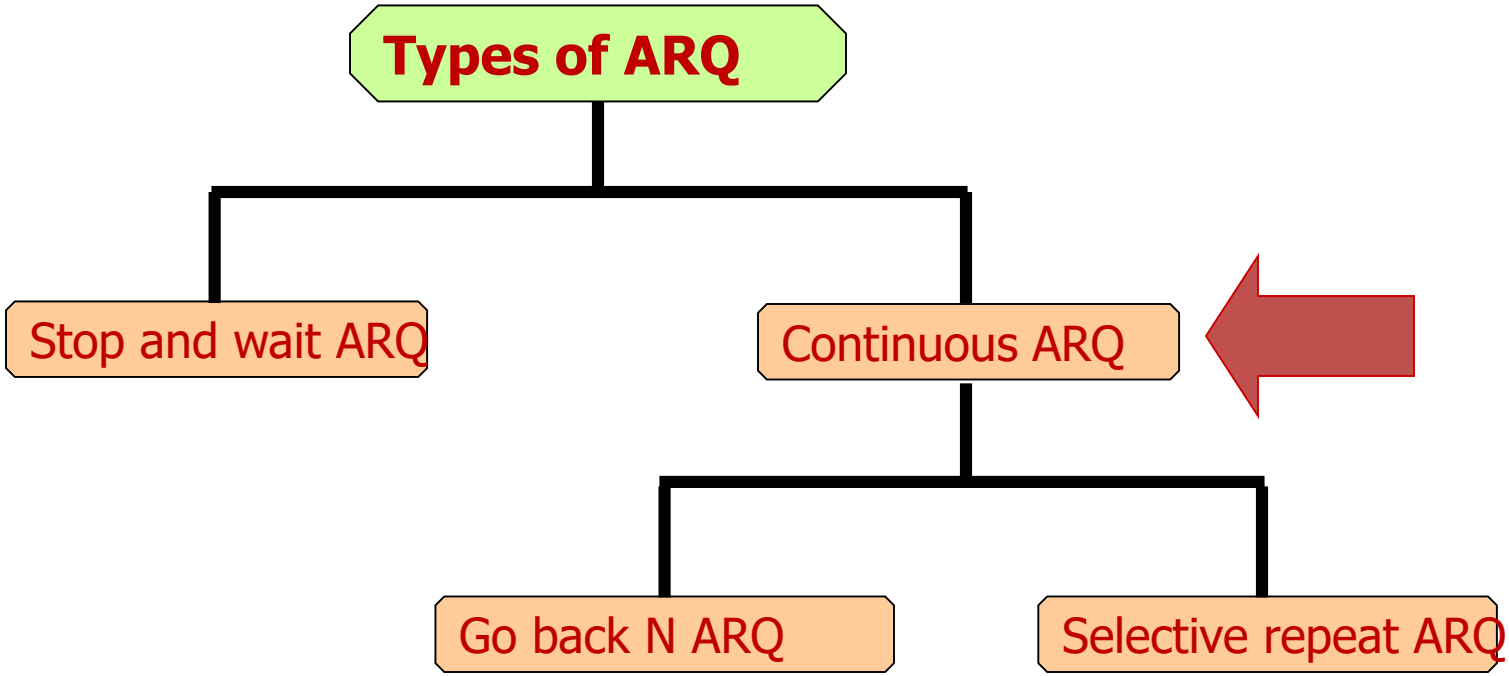
Disadvantage of Stop-and-Wait

- In stop-and-wait, at any point in time, there is only one frame that is sent and waiting to be acknowledged.
- This is not a good use of transmission medium.
- To improve efficiency, multiple frames should be in transition while waiting for ACK.
- Two protocol use the above concept,
  - **Go-Back-N ARQ**
  - **Selective Repeat ARQ**

Types of ARQ


Types of ARQ
Stop and wait ARQ
Continuous ARQ
Go back N ARQ
Selective repeat ARQ

Continuous ARQ

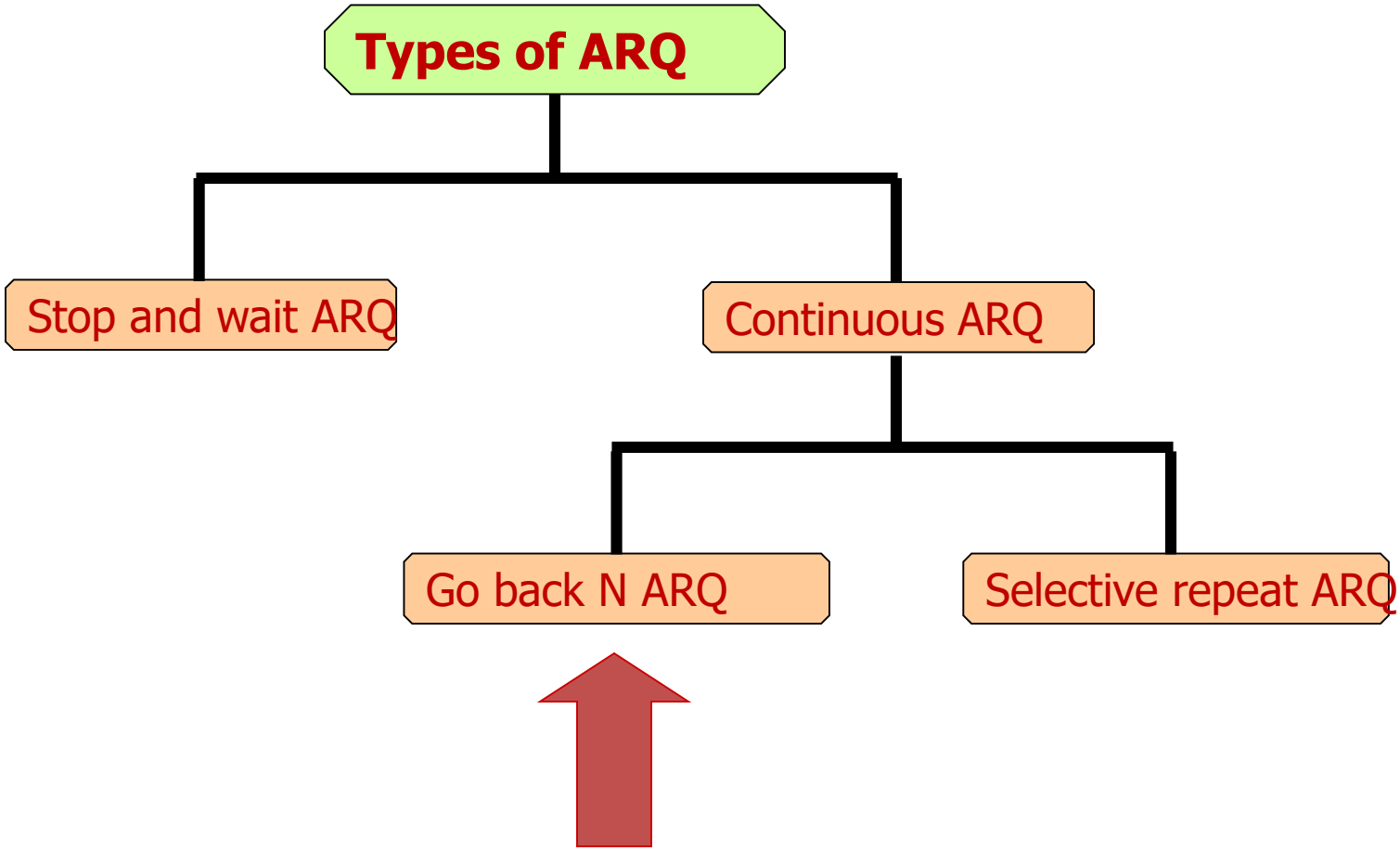
- The blocks are transmitted continuously without waiting for ACK.
- Upper ceiling is put on the number of unacknowledged messages that are outstanding.
- This approach is called “Sliding Window Scheme“.
- The size of the window is the maximum number of unacknowledged messages permitted.
- Both frame transmission and ACK occur simultaneously.
- This eliminates dead time waiting for ACKs.

Continuous ARQ

Disadvantage of sliding window

- The transmitter must have n buffers to store copies of the n messages in transit that may require retransmission.

Types of ARQ


Types of ARQ
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Continuous ARQ
Go back N ARQ
Selective repeat ARQ

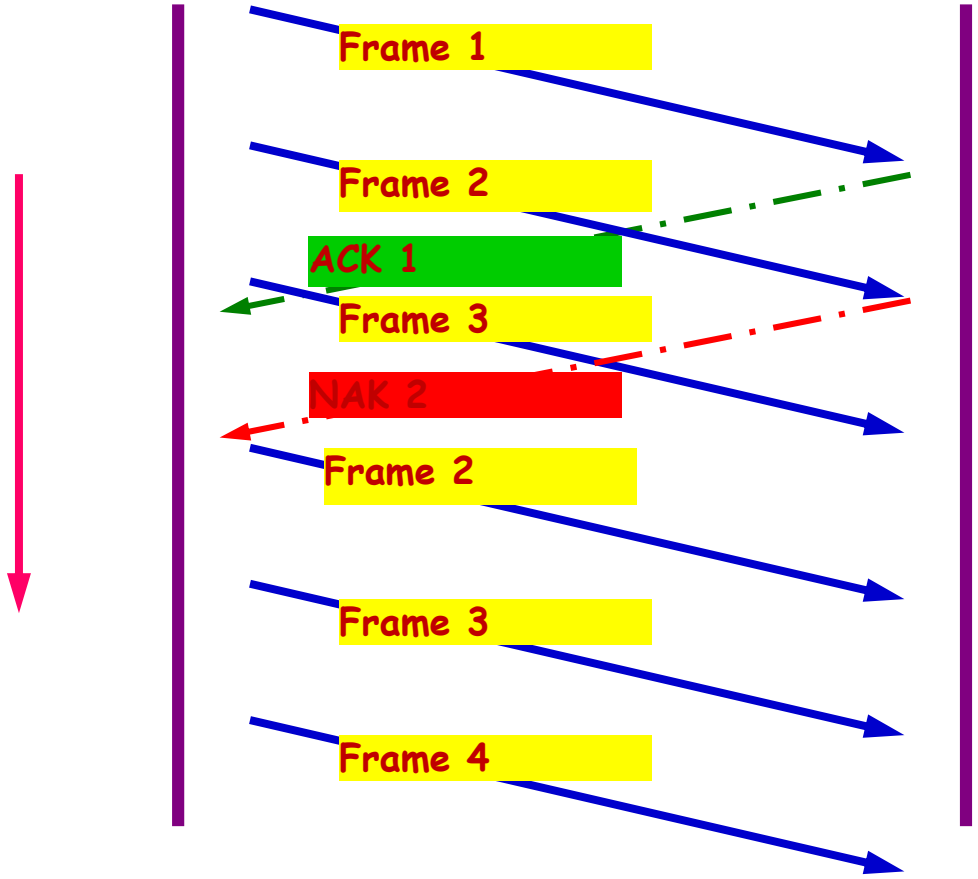
Go–back–N ARQ

- The transmitter must retransmit the block that was detected in error as well as all succeeding blocks.
- This ensures that the blocks at the receiver are in correct sequence.

Disadvantage

- It is inefficient with respect to channel utilization especially at high errors.

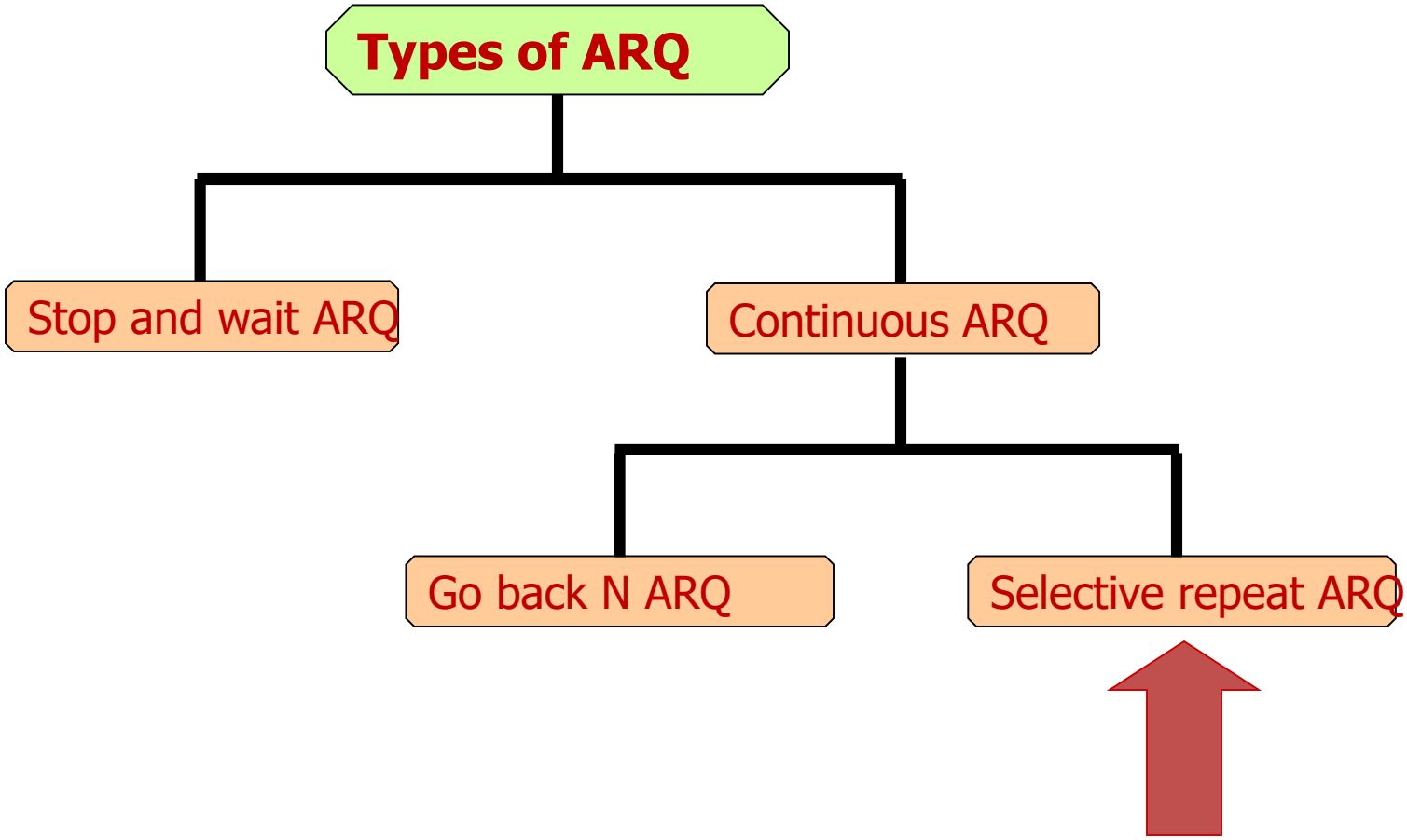
Go–back–N ARQ



Go-Back-N ARQ

- We can send up to W frames before worrying about ACKs.
- We keep a copy of these frames until the ACKs arrive.
- This procedure requires additional features to be added to Stop-and-Wait ARQ.

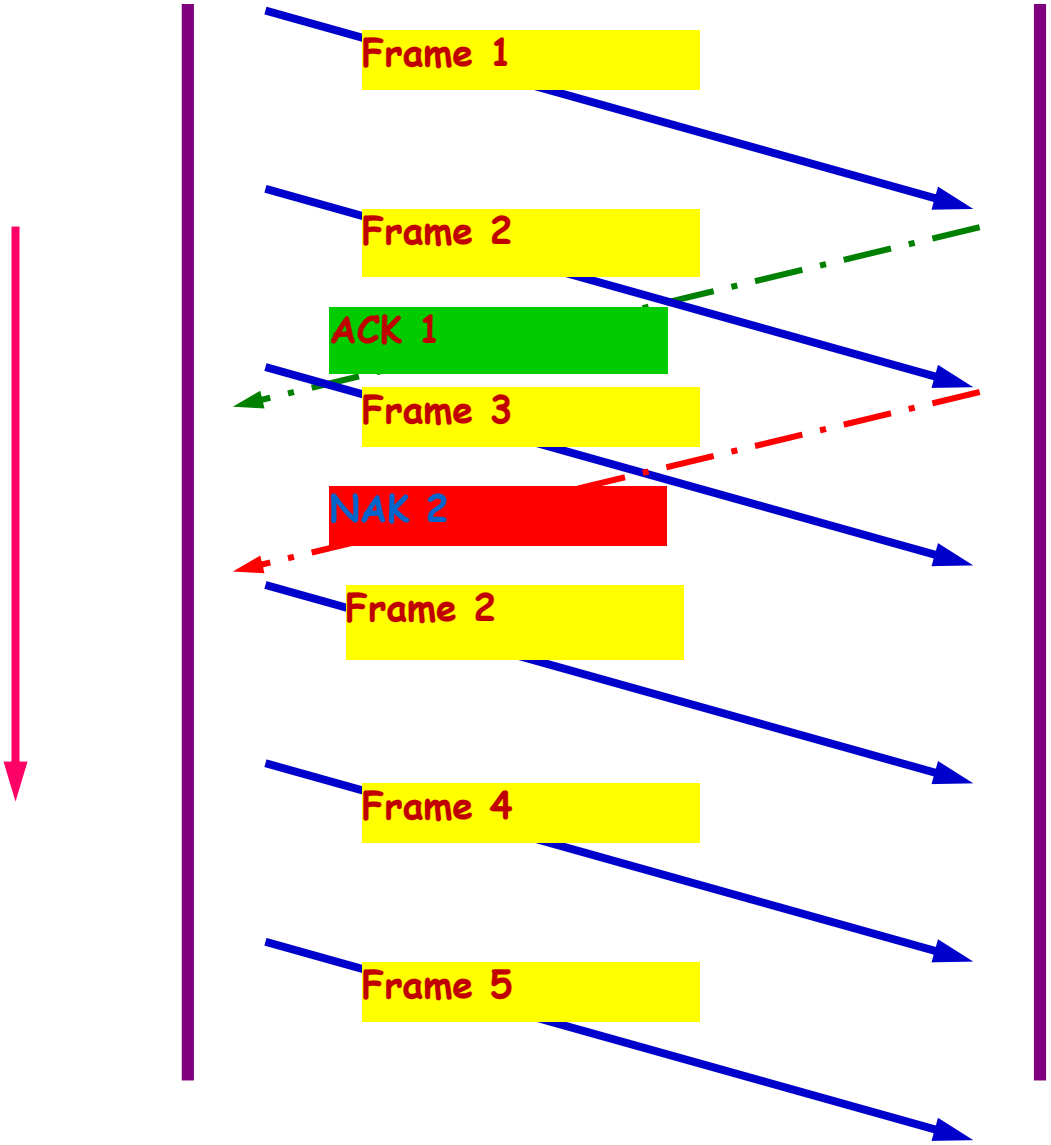
Types of ARQ


Types of ARQ
Stop and wait ARQ
Continuous ARQ
Go back N ARQ
Selective repeat ARQ

Selective repeat ARQ

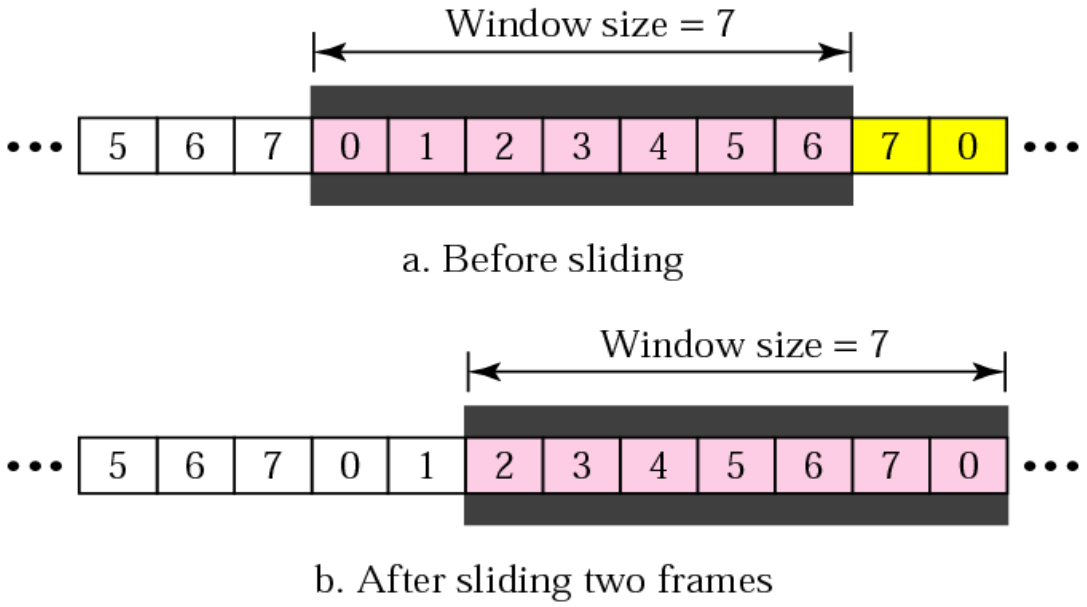
- Only the block detected in error is retransmitted.
- It is much more efficient with respect to channel utilization.
- More buffer space and more complex processing are required at the receiving node.
- All correctly received blocks are stored and then reassembled into the correct sequence.
- A further drawback is that multiple errors in different blocks can lead to very complex recovery sequences.
- Although selective repeat ARQ is more efficient but Go-back-N is more widely implemented.

Selective repeat ARQ



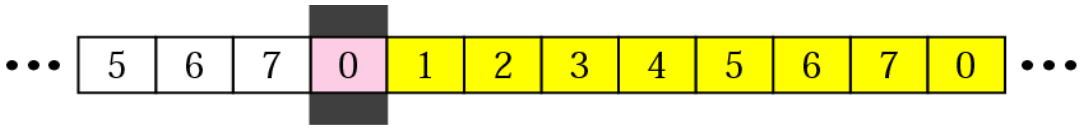
Sender Sliding Window

- At the sending site, to hold the outstanding frames until they are acknowledged, we use the concept of a window.
- The size of the window is at most 2^m -1 where m is the number of bits for the sequence number.
- Size of the window can be variable, e.g. TCP.
- The window slides to include new unsent frames when the correct ACKs are received

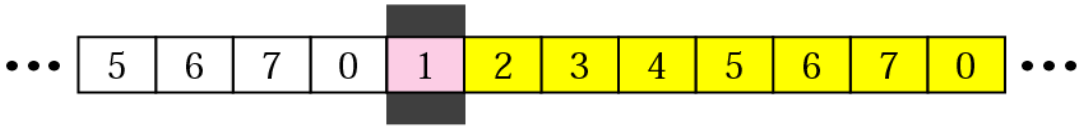


Receiver Sliding Window

- Size of the window at the receiving site is always 1 in this protocol.
- Receiver is always looking for a specific frame to arrive in a specific order.
- Any frame arriving out of order is discarded and needs to be resent.
- Receiver window slides as shown in fig. Receiver is waiting for frame 0 in part a.



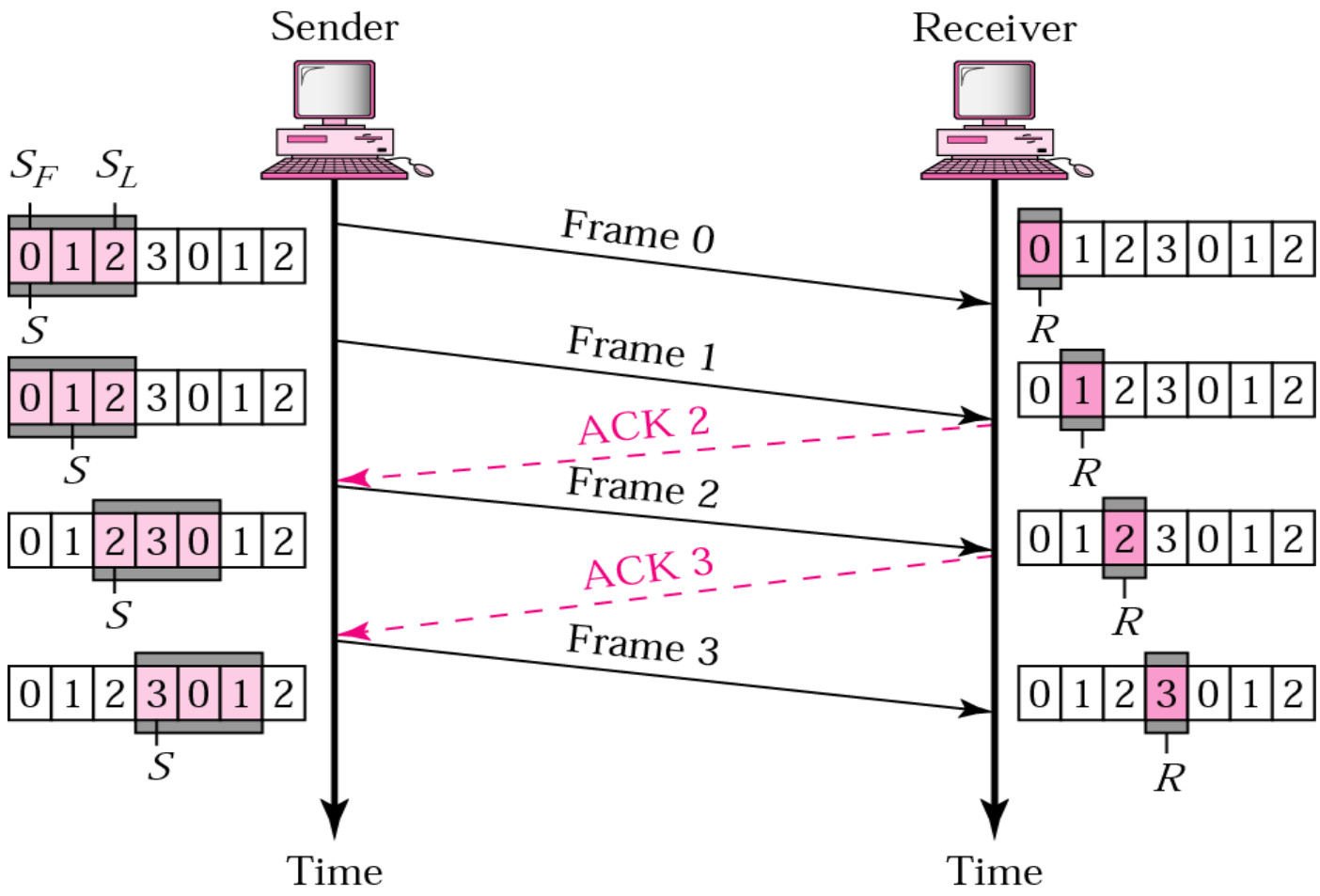
a. Before sliding



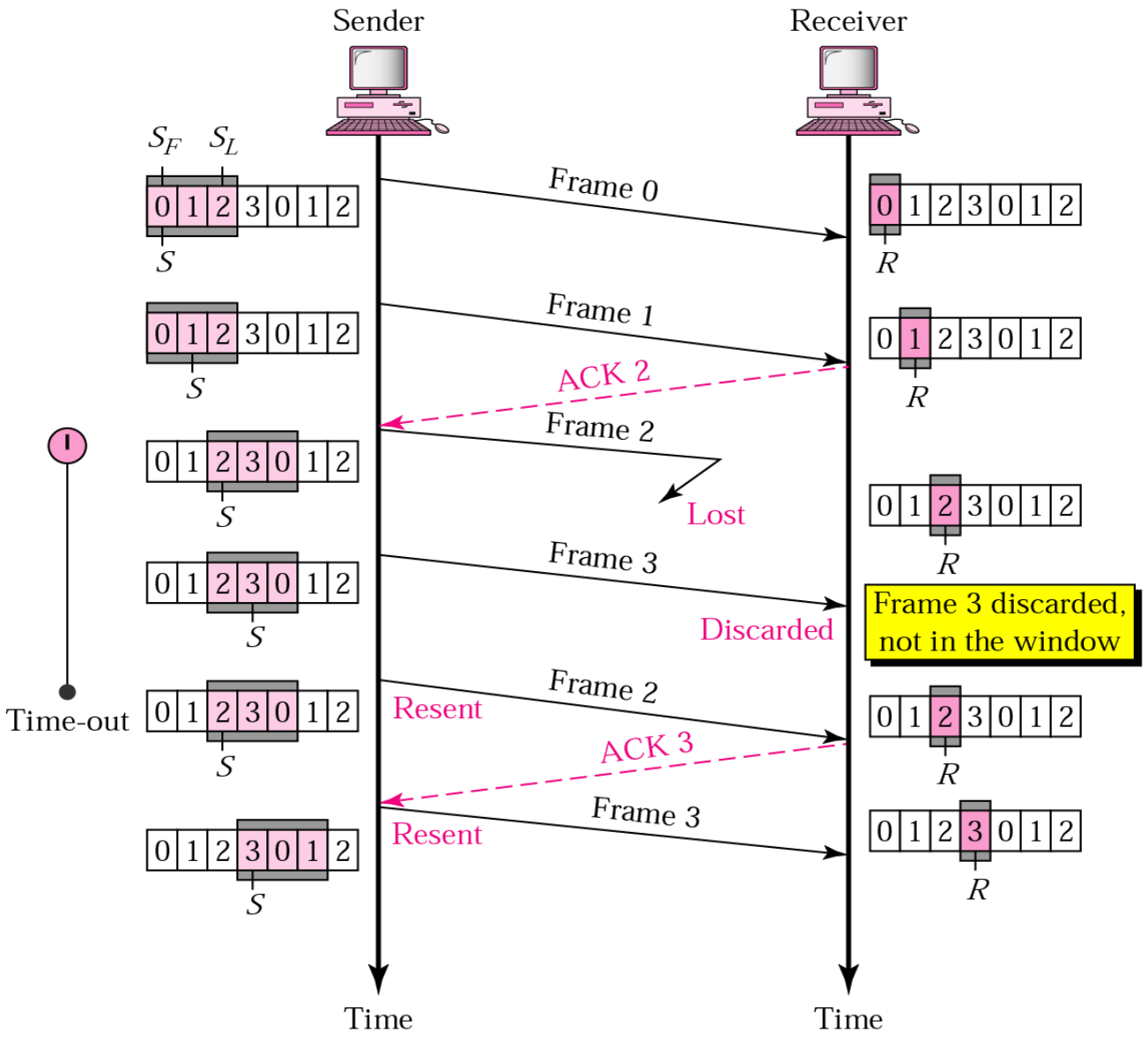
b. After sliding

Go-Back-N ARQ, normal operation

- The sender keeps track of the outstanding frames and updates the variables and windows as the ACKs arrive.



Go-Back-N ARQ, lost frame



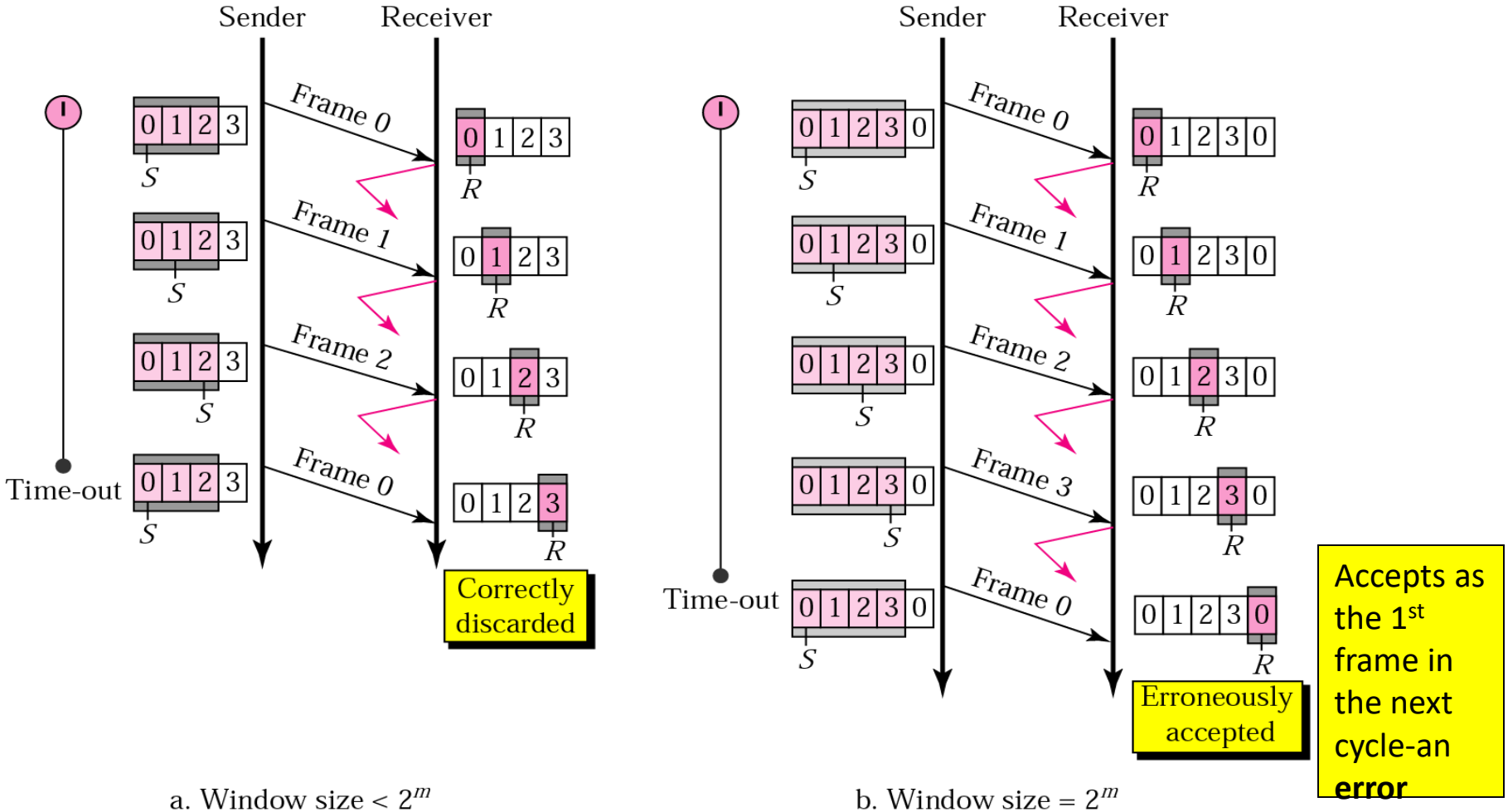
- Frame 2 is lost
- When the receiver receives frame 3, it discards frame 3 as it is expecting frame 2 (according to window).
- After the timer for frame 2 expires at the sender site, the sender sends frame 2 and 3. (go back to 2)

Go-Back-N ARQ, damaged/lost/delayed ACK

- If an ACK is damaged/lost, we can have two situations:
- If the next ACK arrives before the expiration of any timer, there is no need for retransmission of frames because ACKs are cumulative in this protocol.
- If ACK1, ACK2, and ACk3 are lost, ACK4 covers them if it arrives before the timer expires.
- If ACK4 arrives after time-out, the last frame and all the frames after that are resent.
- Receiver never resends an ACK.
- A delayed ACK also triggers the resending of frames

Go-Back-N ARQ, sender window size

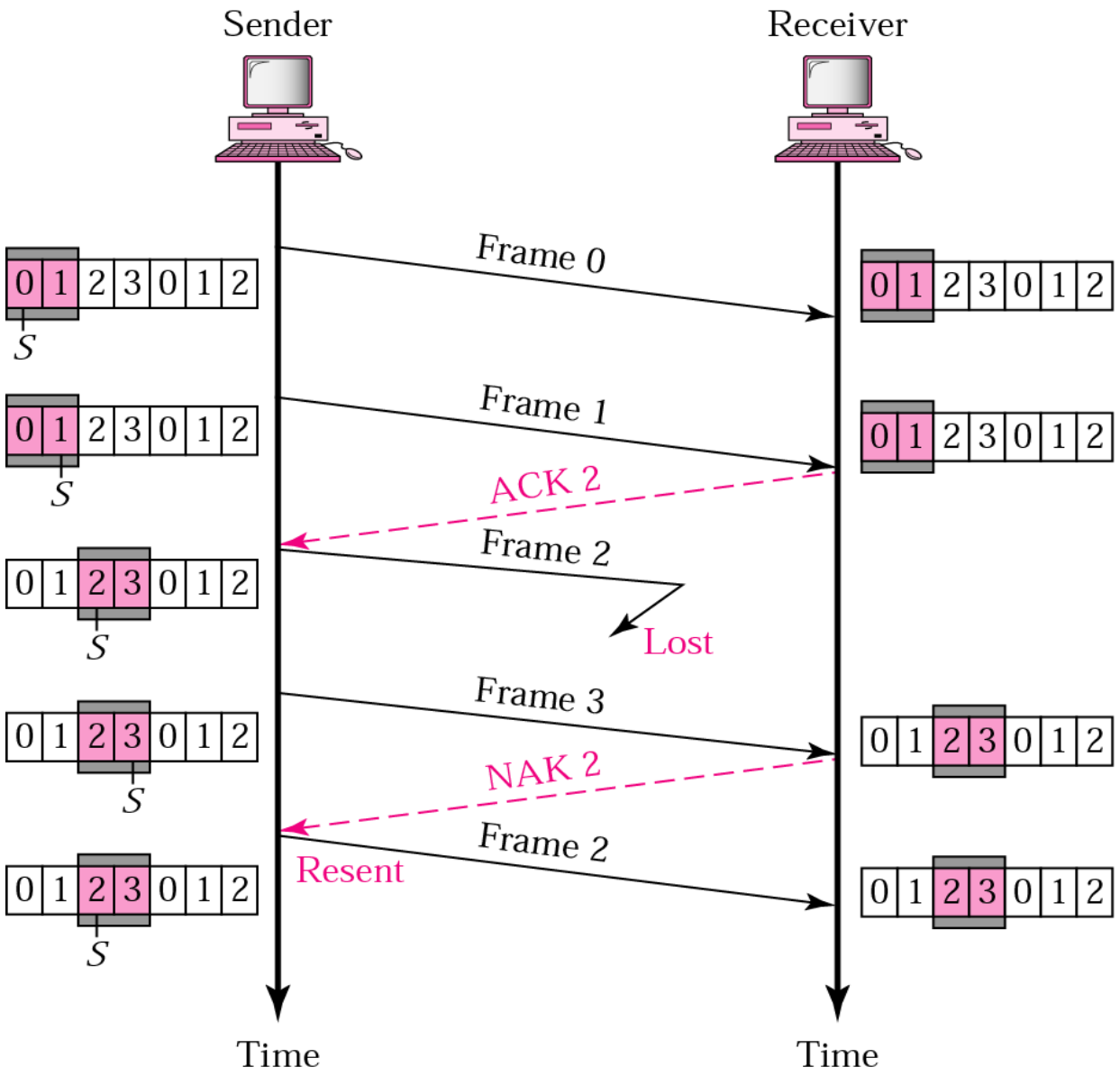
- Size of the sender window must be less than 2^m. Size of the receiver is always 1. If m = 2, window size = $2^m - 1 = 3$.
- Fig compares a window size of 3 and 4.



a. Window size < 2^m

b. Window size = 2^m

Selective Repeat ARQ, lost frame



- Frames 0 and 1 are accepted when received because they are in the range specified by the receiver window. Same for frame 3.
- Receiver sends a NAK2 to show that frame 2 has not been received and then sender resends only frame 2 and it is accepted as it is in the range of the window.